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ASPECT RATIO EFFECTS ON THE AERODYNAMIC AND HEAT-TRANSFER CHARACTERISTICS OF THE SNAP-29 FUEL BLOCK AT MACH NUMBER 8

R. H. Burt, ARO, Inc.

and

D. C. Reynolds, Second Lieutenant, USAF

February 1968

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*Rec. AF letter
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ASPECT RATIO EFFECTS ON THE AERODYNAMIC
AND HEAT-TRANSFER CHARACTERISTICS OF THE
SNAP-20 FUEL BLOCK AT MACH NUMBER 8

R. H. Burt, ARO, Inc.

and

D. C. Reynolds, Second Lieutenant, USAF

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*Per AF Letter
dated 23 Jan., 75
Signed William D. Cole*

FOREWORD

The work reported herein was done at the request of the Atomic Energy Commission (AEC) for the Martin Company, Baltimore Division, under Program Area 921D, AEC Order No. AL-67-255.

The test results presented herein were obtained by ARO, Inc. (a subsidiary of Sverdrup & Parcel and Associates, Inc.), contract operator of the Arnold Engineering Development Center (AEDC), Air Force Systems Command (AFSC), Arnold Air Force Station, Tennessee, under Contract AF40(600)-1200. The tests were conducted from October 10 to November 10, 1967, under ARO Project No. VB1841, and the manuscript was submitted for publication on January 11, 1968.

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This technical report has been reviewed and is approved.

Donald H. Meyer
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ABSTRACT

Selected test results are presented to show the effect of aspect ratio on the aerodynamic and heat-transfer characteristics of the SNAP-29 fuel block which is a flat plate configuration with cylindrical edges. Static-force and moment and heat-transfer data were measured on models having aspect ratios of 1.7 and 3.2 at angles of attack from 0 to 90 deg and yaw rotations from 0 to 90 deg. The tests were conducted at Mach number 8 and Reynolds numbers from 0.22 to 0.46 million, based on model length.

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NOMENCLATURE

| | |
|-----------|--|
| AR | Aspect ratio, s/ℓ |
| b | Model skin thickness, ft |
| C_{A_t} | Total axial-force coefficient (not corrected for base pressure), total axial force/ $q_\infty S$ |
| C_ℓ | Rolling-moment coefficient, rolling moment/ $q_\infty S\ell$ |
| C_m | Pitching-moment coefficient, pitching moment/ $q_\infty S\ell$ |
| C_N | Normal-force coefficient, normal force/ $q_\infty S$ |
| C_n | Yawing-moment coefficient, yawing moment/ $q_\infty S\ell$ |
| C_Y | Side-force coefficient, side force/ $q_\infty S$ |
| c | Specific heat of model material, Btu/lb-°R |
| H | Enthalpy, Btu/lb |
| ℓ | Reference length (see Fig. 1), in. |
| M | Mach number |
| p | Pressure, psia |
| q | Dynamic pressure, psia |
| \dot{q} | Heat-transfer rate, Btu/ft ² -sec |
| Re_ℓ | Free-stream Reynolds number based on model reference length |
| S | Reference area (see Fig. 1), in. ² |

| | |
|--------------------|---|
| St | Stanton number |
| St _{F.R.} | Theoretical Stanton number based on Fay and Riddell theory and a 1-ft radius sphere |
| s | Span, in. |
| T | Temperature, °R |
| t | Time, sec |
| u | Velocity, ft/sec |
| w | Density of model material, lb/ft ³ |
| x | Distance from model leading edge, in. |
| z | Model thickness (see Fig. 1), in. |
| α | Angle of attack, deg |
| γ | Model rotation angle (see Fig. 2c), deg |
| ρ | Density, lb/ft ³ |

SUBSCRIPTS

| | |
|----------|------------------------------------|
| o | Tunnel stilling chamber conditions |
| s | Model stagnation conditions |
| w | Model wall conditions |
| ∞ | Free-stream conditions |

SECTION I INTRODUCTION

The fuel block of the SNAP-29 polonium fueled radioisotopic generator is a flat plate with rounded edges and corners, the edge shape having been determined from previous testing on a low aspect ratio (approximately 1.1) configuration, Ref. 1. It was assumed in the previous tests as in the present tests that the fuel block would be ejected from the generator unit prior to re-entry and only the fuel block would be designed for intact re-entry. It is necessary, therefore, that the aerodynamic and heat-transfer characteristics of the fuel block be known so that trajectory and aeroheating predictions can be made. Following the previous tests and selection of the edge shape, other configurations of different aspect ratio are being considered. Two of these configurations, designated M₂ and M₃ and having aspect ratios of 3.2 and 1.7, respectively, were investigated in the present tests to provide part of the necessary information required for selection of an optimum fuel block configuration for SNAP-29.

The tests were conducted in the 50-in. hypersonic tunnel (Gas Dynamic Wind Tunnel, Hypersonic (B)) of the von Kármán Gas Dynamics Facility (VKF), AEDC, at Mach number 8 and Reynolds numbers based on model length of 0.26 and 0.46 million for the force and moment tests and 0.22 and 0.40 million for the heat-transfer tests. Model rotation angles (yaw rotations) from 0 to 90 deg were investigated at angles of attack from 0 to 90 deg.

SECTION II APPARATUS

2.1 WIND TUNNEL

Tunnel B is a continuous, closed-circuit, variable density wind tunnel with an axisymmetric contoured nozzle and a 50-in. -diam test section. The tunnel operates at a nominal Mach number of 6 or 8 at stagnation pressures from 20 to 280 and from 50 to 900 psia, respectively, at stagnation temperatures up to 1350°R. The model may be injected into the tunnel for a test run and then retracted for model cooling or model changes without interrupting the tunnel flow. A description of the tunnel may be found in Ref. 2.

2.2 MODELS AND SUPPORT

The SNAP-29 fuel block is basically a flat plate with rounded edges and corners. Four force models and one heat-transfer model were supplied by the Martin Company, and the basic dimensions of each model are shown in Fig. 1 along with the full-scale dimensions. The model aspect ratios were 3.2 and 1.7 which comprised configurations M₂ and M₃, respectively.

The force models and four balance-model adapters (provided to obtain the desired angle-of-attack range) were constructed of 321 stainless steel and are shown in Fig. 2a. The 0.74-scale M₂ model was tested at angles of attack from -7 to 35 deg using the 8- and 22.5-deg adapters. The 0.74-scale M₃ model was tested only with the 8-deg adapter up to 23-deg angle of attack because of tunnel blockage. Angles of attack from 30 to 90 deg were obtained with the 0.50-scale M₂ and 0.37-scale M₃ models by using the 45- and 75-deg adapters. Model rotation angles from 0 to 90 deg in 15-deg increments were accomplished by simply rotating each model on the balance-model adapter about the model geometric center. The balance was installed inside the 8-deg adapter; however, the 22.5-, 45-, and 75-deg adapters required a sting-mounted windshield (Fig. 2a) to shield the balance from the airstream. The 0.74-scale M₂ model is shown installed in the tunnel in Fig. 2b. The model force and moment reference system is shown in Fig. 2c.

The 0.40-scale heat-transfer model is shown in Fig. 3. The basic model simulated configuration M₂, and the M₃ configuration was formed by adding an extension, which was not instrumented, to the basic model (see Fig. 3a). The basic model was instrumented with 94 Chromel®-Alumel® thermocouples. Both the basic model and the extension were of thin skin construction, nominally 0.037 in. thick, and were fabricated from Inconel 600. A phenolic honeycomb, which had holes enlarged to 0.25-in. diameter at each thermocouple location to minimize conduction losses, was bonded to the model skin to provide additional support for the flattened areas of the model. The model was attached to an adjustable sting which provided prebends of 15, 45, and 75 deg relative to the tunnel centerline. These prebends with the ± 15 -deg travel of the model support system provided an angle-of-attack range from 0 to 90 deg. Model rotation angles of 0, -45, -60.2, -72.5, -90, -180, -240.2, and -270 deg were obtained by rotating the model at the sting-to-model attachment. Rotations of -180, -240.2, and -270 deg were necessary in order to locate the instrumented portion of configuration M₃ where the noninstrumented portion was located on rotations of 0, -60.2, and -90 deg, respectively.

2.3 INSTRUMENTATION

2.3.1 Force

Model forces and moments were measured with a six-component, moment-type, strain-gage balance supplied and calibrated by VKF. Before the test, combined balance static loadings were applied, simulating the model loading range anticipated during the test. The uncertainties listed below correspond to the differences between the applied loads and the values calculated by the final data reduction balance equations.

| <u>Balance Component</u> | <u>Design Load</u> | <u>Maximum Static Loads</u> | <u>Uncertainties</u> |
|--------------------------|--------------------|-----------------------------|----------------------|
| Normal force, lb | ±200 | ± 60 | ±0.40 |
| Pitching moment, in. -lb | ±680 | ±240 | ±1.20 |
| Side force, lb | ±200 | ± 50 | ±0.35 |
| Yawing moment, in. -lb | ±680 | ± 75 | ±1.50 |
| Rolling moment, in. -lb | ±100 | ± 50 | ±0.45 |
| Axial force, lb | 50 | 100 | ±0.35 |

2.3.2 Heat Transfer

The heat-transfer model surface temperature was measured with thermocouples welded into holes in the model surface. Thermocouple outputs were recorded on magnetic tape, at a rate of 20 times per second, from the start of the injection cycle until about 2 sec after the model reached the tunnel centerline. From calibrations of typical thermocouple wires and a knowledge of the system sensitivity and noise level, the precision of the VKF temperature recording system is estimated to have been $\pm 0.2^\circ\text{R}/\text{sec}$ or ± 2 percent, whichever was greater.

Model flow field schlieren photographs were obtained during all tests. Figure 4 shows typical photographs.

SECTION III PROCEDURE

3.1 TEST CONDITIONS

The tests were conducted at the following conditions:

| M_∞ | $Re_\ell \times 10^{-6}$ | p_O , psia | T_O , °R | q_∞ , psia | $St_{F,R}$ |
|------------|--------------------------|--------------|------------|-------------------|------------|
| 7.86 | 0.26 | 70 | 1165 | 0.35 | --- |
| 7.86 | 0.46 | 70 | 1165 | 0.35 | --- |
| 7.89 | 0.26 | 120 | 1205 | 0.59 | --- |
| 7.90 | 0.46 | 150 | 1230 | 0.73 | --- |
| 7.89 | 0.22 | 120 | 1205 | 0.59 | 0.0067 |
| 7.89 | 0.40 | 120 | 1205 | 0.59 | 0.0067 |

A complete test summary is presented in Table I.

3.2 DATA REDUCTION

The heat-transfer data were reduced using the temperature-time histories from the thermocouples and the equation

$$\dot{q} = wbc \frac{dT_w}{dt}$$

where

$$w = 525.3 \text{ lb/ft}^3$$

b = measured skin thickness at each thermocouple
(nominally 0.0030 ft)

$$c = 1.4861 \times 10^{-2} + 3.2470 \times 10^{-4} T_w - 3.8572 \times 10^{-7} T_w^2 \\ + 1.6815 \times 10^{-10} T_w^3, \text{ Btu/lb-}^\circ\text{R}$$

This equation neglects conduction and radiation losses. The values of w , b , and c were supplied by the Martin Company. Stanton numbers were computed using the equation

$$St = \frac{\dot{q}}{\rho_\infty u_\infty (H_o - H_w)}$$

and these Stanton numbers were ratioed to a theoretical Stanton number, $St_{F,R}$, computed from the Fay and Riddell theory (Ref. 3) for the stagnation point heating of a sphere having a 1-ft radius. The heat-transfer data presented were evaluated at the time the model reached tunnel centerline.

Measured leading edge heat-transfer values were compared with a theoretical Stanton number computed for the stagnation line on an unswept cylinder using the theory of Ref. 3 to obtain the stagnation point

heating rate on a sphere having the same radius as the cylinder, 0.0167 ft, and the equation

$$(\dot{q}_w)_{\text{cylinder}} = 0.729 (\dot{q}_w)_{\text{sphere}}$$

where the constant, 0.729, was obtained from Ref. 4, p. 300, Eq. (8.3.20). Theoretical flat plate Stanton numbers for $\alpha = 0$ were computed using the method of Ref. 5.

SECTION IV RESULTS AND DISCUSSION

The aerodynamic characteristics of configuration M₂, aspect ratio = 3.2, are presented in Fig. 5 for model rotation angles of 0, 30, 45, 60, and 90 deg. It should be noted that the force and moment reference system used for the data presented is independent of the model rotation angle, γ . Increasing γ resulted in decreasing C_N which was first observed near $40 < \alpha < 75$ deg; however, increasing γ to 90 deg resulted in C_N being definitely lower at all angles of attack up to approximately 80 deg (Fig. 5a). Large increases in C_m at angles of attack from approximately 25 to 40 deg, depending on γ , are attributed to a center-of-pressure shift caused by bow shock detachment which was discussed in Ref. 1. The peak values of C_m increased with γ resulting in increased stability at the trim angle of attack, $\alpha = 90$ deg. Indicated trim angles of attack slightly less than 90 deg are attributed to a possible misalignment between the model and balance (a misalignment of 0.015 in. would account for the discrepancies shown). The M₂ configuration was longitudinally unstable for all values of γ from $\alpha = 0$ to $\alpha = 60$ deg where it became stable about the $\alpha = 90$ deg trim angle. Systematic decreases in C_{A_t} occurred with increased α and increasing γ as expected. Directional and lateral stability data for configuration M₂, Fig. 5b, show that negative C_Y values were produced for model rotations between 0 and 90 deg with the largest value occurring at $\alpha = 0$ and $\gamma = 30$ deg. C_N was relatively insensitive to variations in α and γ with only slight variations occurring near $35 < \alpha < 65$ deg. It should be noted here that C_Y and C_N in Fig. 5b and C_{A_t} in Fig. 5a are dominated by the model leading edge and variations in these coefficients with γ are basically leading edge sweep effects. Rather large variations in C_l were measured, the largest occurring at $\gamma = 30$ deg. These rolling moments are believed to be caused by the center-of-pressure shift mentioned previously. With the model rotated to an angle between 0 and 90 deg, the center of pressure would shift diagonally across the model as angle of attack varied, inducing a rolling moment; whereas at $\gamma = 0$ and 90 deg, it would shift along the model centerline affecting only the pitching moment.

The effects of aspect ratio on the model aerodynamic characteristics are illustrated in Fig. 6 for $\gamma = 0$ and 60 deg. This figure shows that similar trends were obtained on both M_2 (AR = 3.2) and M_3 (AR = 1.7) with the largest coefficients generally occurring on the higher aspect ratio configuration. It should be noted that evaluation of the effects of varying aspect ratio is somewhat obscured because the model planform area was used as the reference area and some coefficients (C_{At} , C_Y , and C_N) are dominated by the leading edge as previously mentioned.

Heat-transfer distributions along the longitudinal centerline of configuration M_2 are presented in Fig. 7 for model rotations of 0, -45, and -90 deg and angles of attack from 0 to 90 deg. A stagnation line value was computed for the leading edge at $\alpha = 0$ using Refs. 3 and 4 as discussed in Section 3.2. The measured value is shown to be approximately 25 percent lower than predicted. This difference is attributed to conduction losses. Measurements at $\alpha = 0$ on the model flat surface are shown to be in good agreement with predicted flat plate values.

The effect of aspect ratio variation on the heat-transfer distributions along the longitudinal centerline is illustrated in Fig. 8 for $\gamma = 0$ and -90 deg at angles of attack of 0 and 70 deg. These data show that similar results were obtained on both configurations.

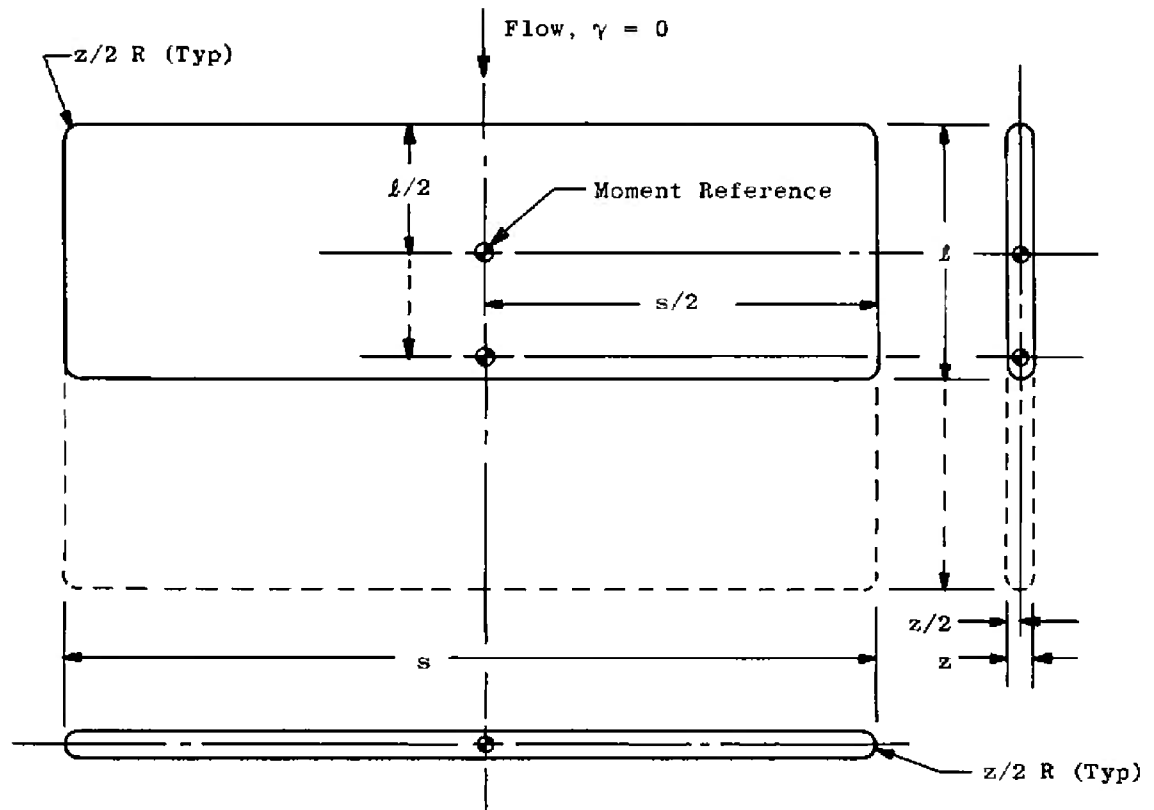
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1. Burt, R. H. and Martindale, W. R. "Aerodynamic Characteristics of Proposed SNAP-29 Fuel Block Configurations at Mach Number 8." AEDC-TR-67-61 (AD813438), April 1967.
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3. Fay, J. A. and Riddell, F. R. "Theory of Stagnation Point Heat Transfer in Dissociated Air." Journal of the Aeronautical Sciences, Vol. 25, February 1958, pp. 73-85.
4. Hayes, W. D. and Probstein, R. F. Hypersonic Flow Theory. Academic Press, New York, 1959.
5. Harms, Richard J., Schmidt, Craig M., Hanawalt, Arnold J., and Schmitt, Durwin A. "A Manual for Determining Aerodynamic Heating of High-Speed Aircraft." Bell Aircraft Corporation Report No. 7006-3352-001, Vol. 1, June 1959.

APPENDIXES

I. ILLUSTRATIONS

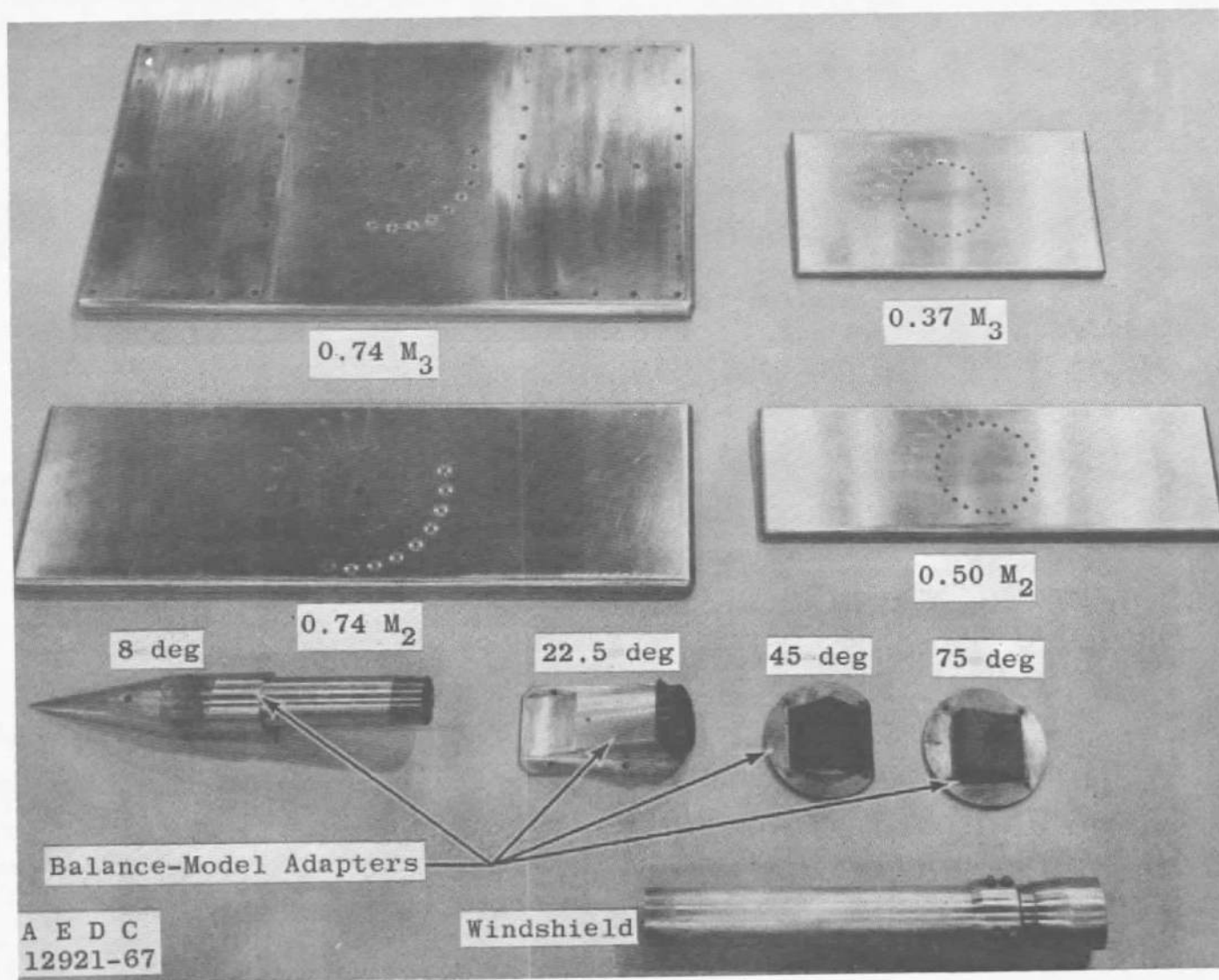
II. TABLES



Solid Lines Show Configuration M_2
Dashed Lines Show Configuration M_3
Moment Reference Located at Geometric Center
of Each Force Model

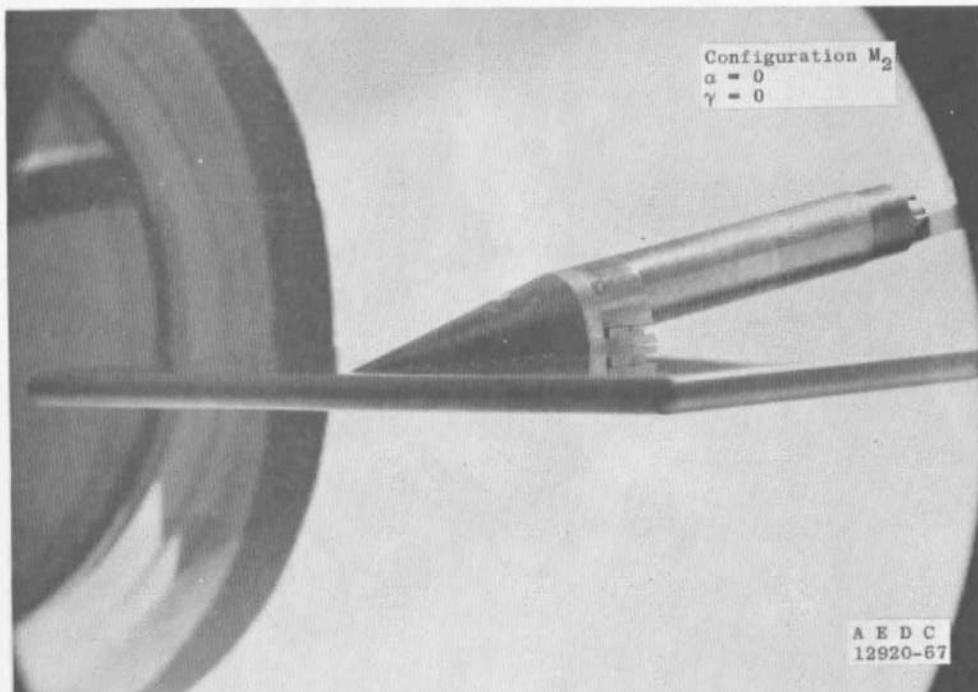
| Type Model | Configuration | Scale | l , in. | s , in. | z , in. | S , in. ² |
|---------------|---------------|-------|-----------|-----------|-----------|------------------------|
| Full Scale | M_2 | 1.00 | 10.32 | 32.68 | 1.00 | 337.3 |
| Force | M_2 | 0.74 | 7.64 | 24.19 | 0.74 | 184.8 |
| Force | M_2 | 0.50 | 5.16 | 16.34 | 0.50 | 84.3 |
| Heat Transfer | M_2 | 0.40 | 4.13 | 13.07 | 0.40 | 54.0 |
| Full Scale | M_3 | 1.00 | 18.74 | 32.68 | 1.00 | 612.4 |
| Force | M_3 | 0.74 | 13.87 | 24.19 | 0.74 | 335.5 |
| Force | M_3 | 0.37 | 6.94 | 12.09 | 0.37 | 83.9 |
| Heat Transfer | M_3 | 0.40 | 7.50 | 13.07 | 0.40 | 98.0 |

Fig. 1 Model Geometry

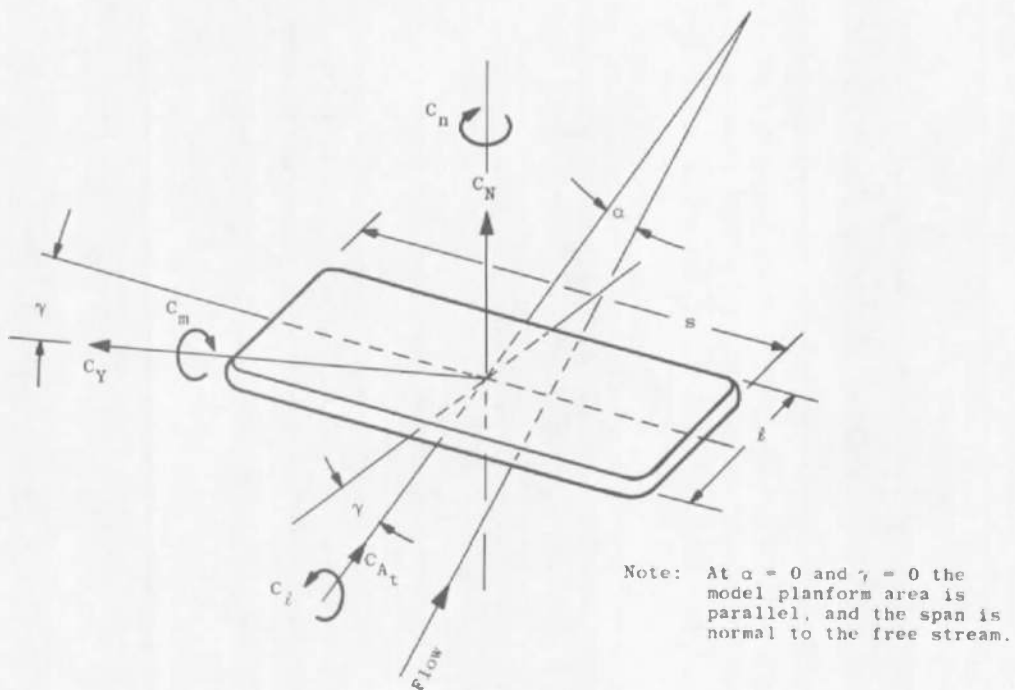


a. Photograph of Models and Balance-Model Adapters

Fig. 2 Force Models

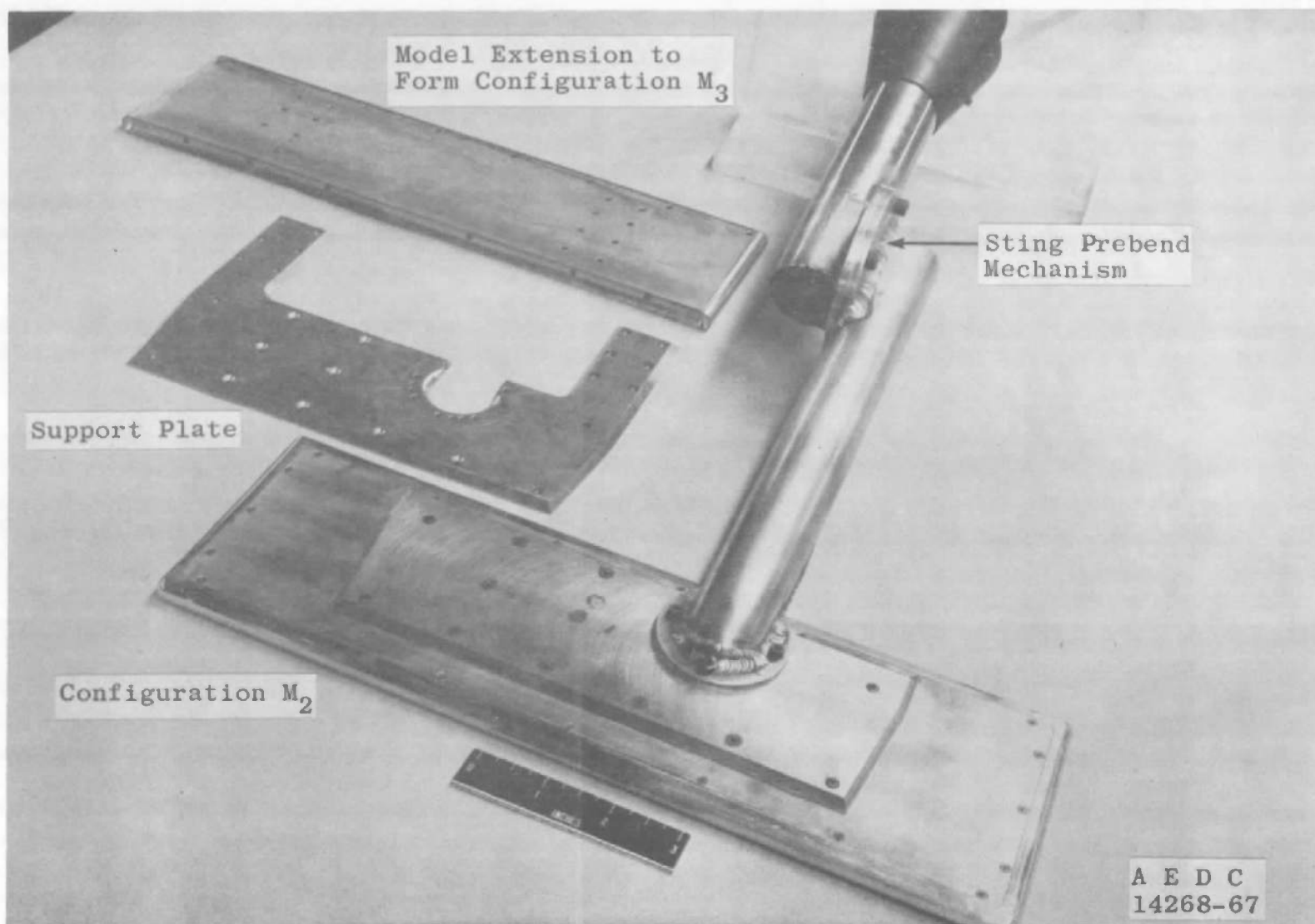


b. Model Installation Photograph

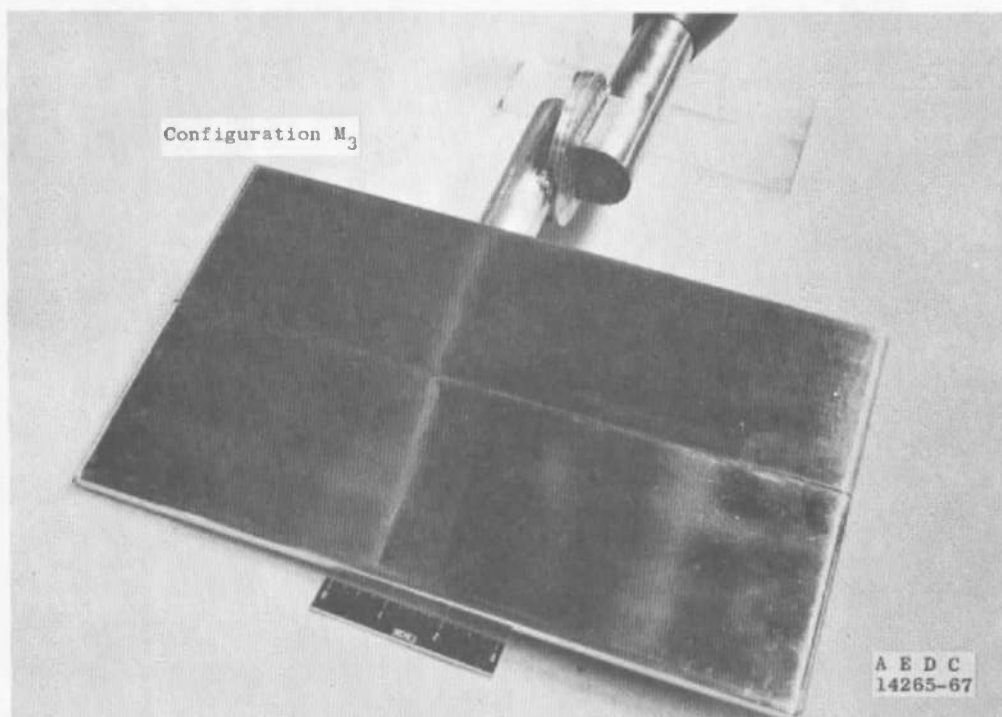
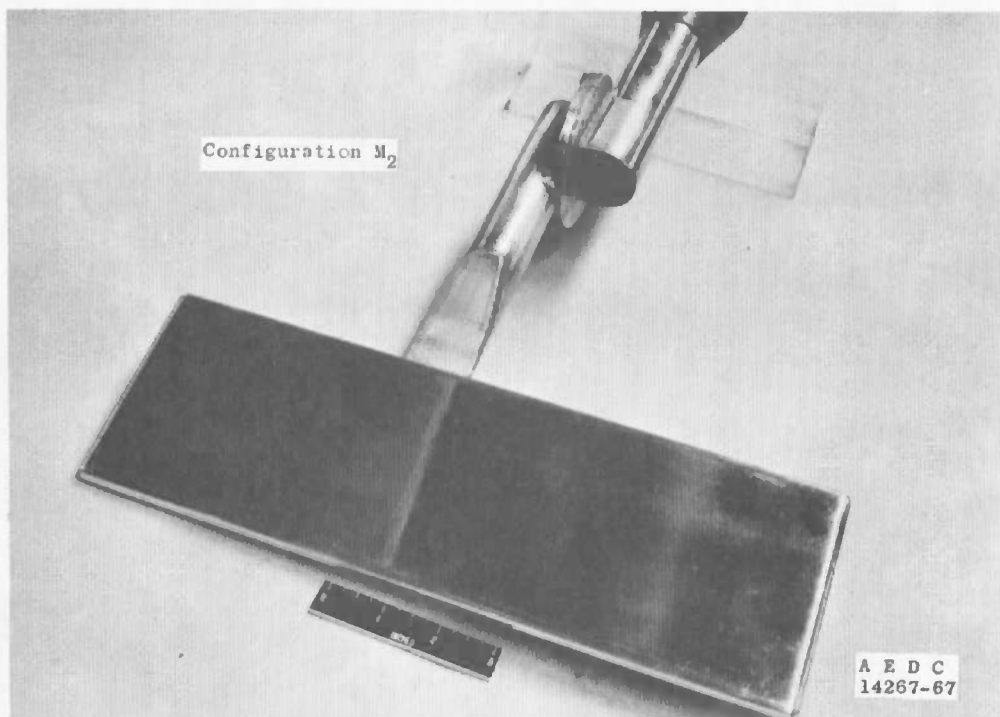


c. Force and Moment Reference System

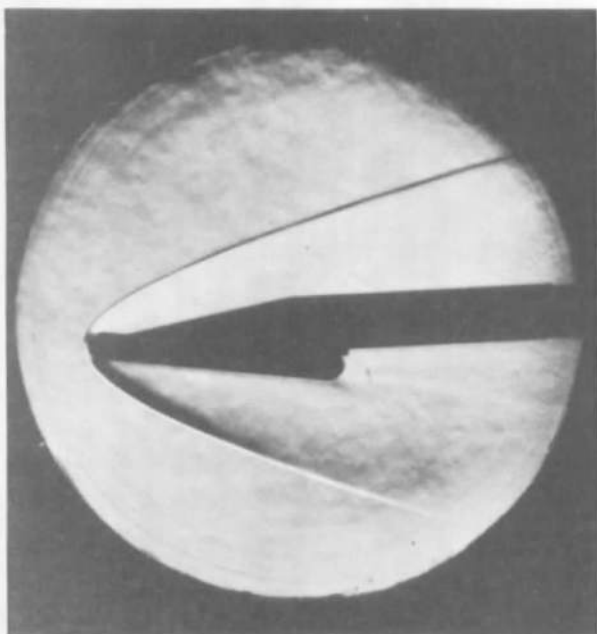
Fig. 2 Concluded



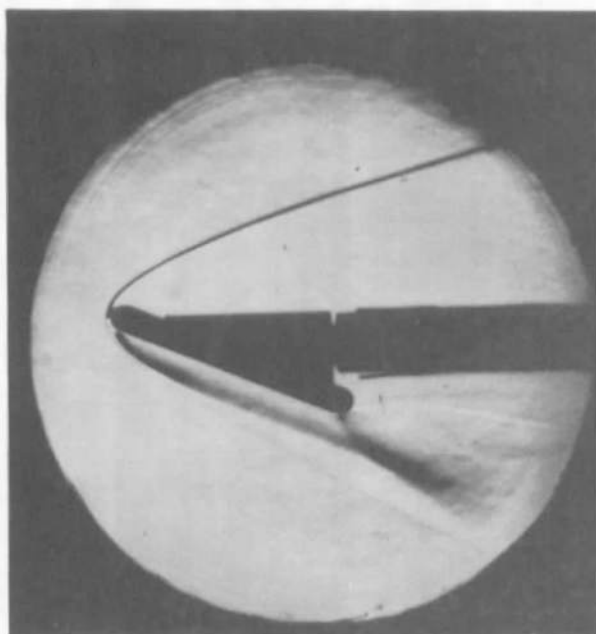
a. Photograph Showing Model Components
Fig. 3 Heat-Transfer Model



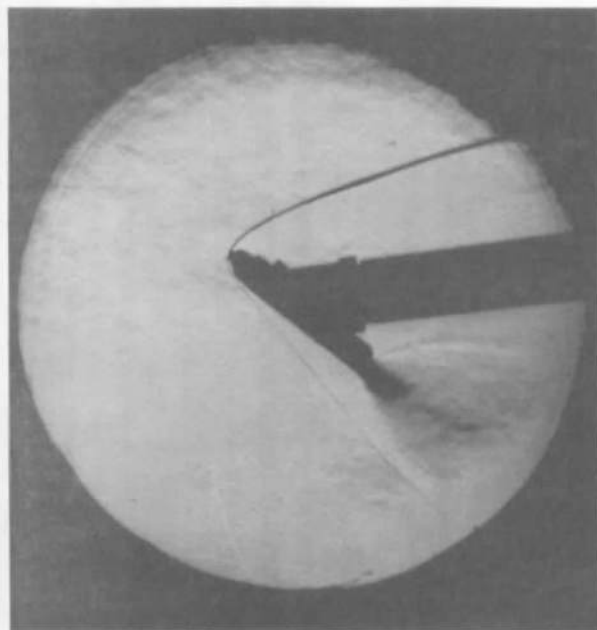
b. Photographs Showing Configurations M_2 and M_3
Fig. 3 Concluded



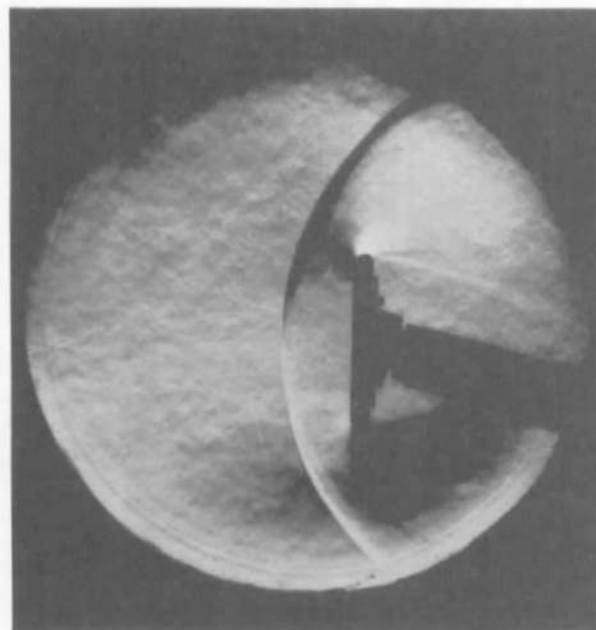
$\alpha = 5 \text{ deg}$
8-deg Balance-Model
Adapter, 0.74 Scale



$\alpha = 20 \text{ deg}$
22.5-deg Balance-Model
Adapter, 0.74 Scale

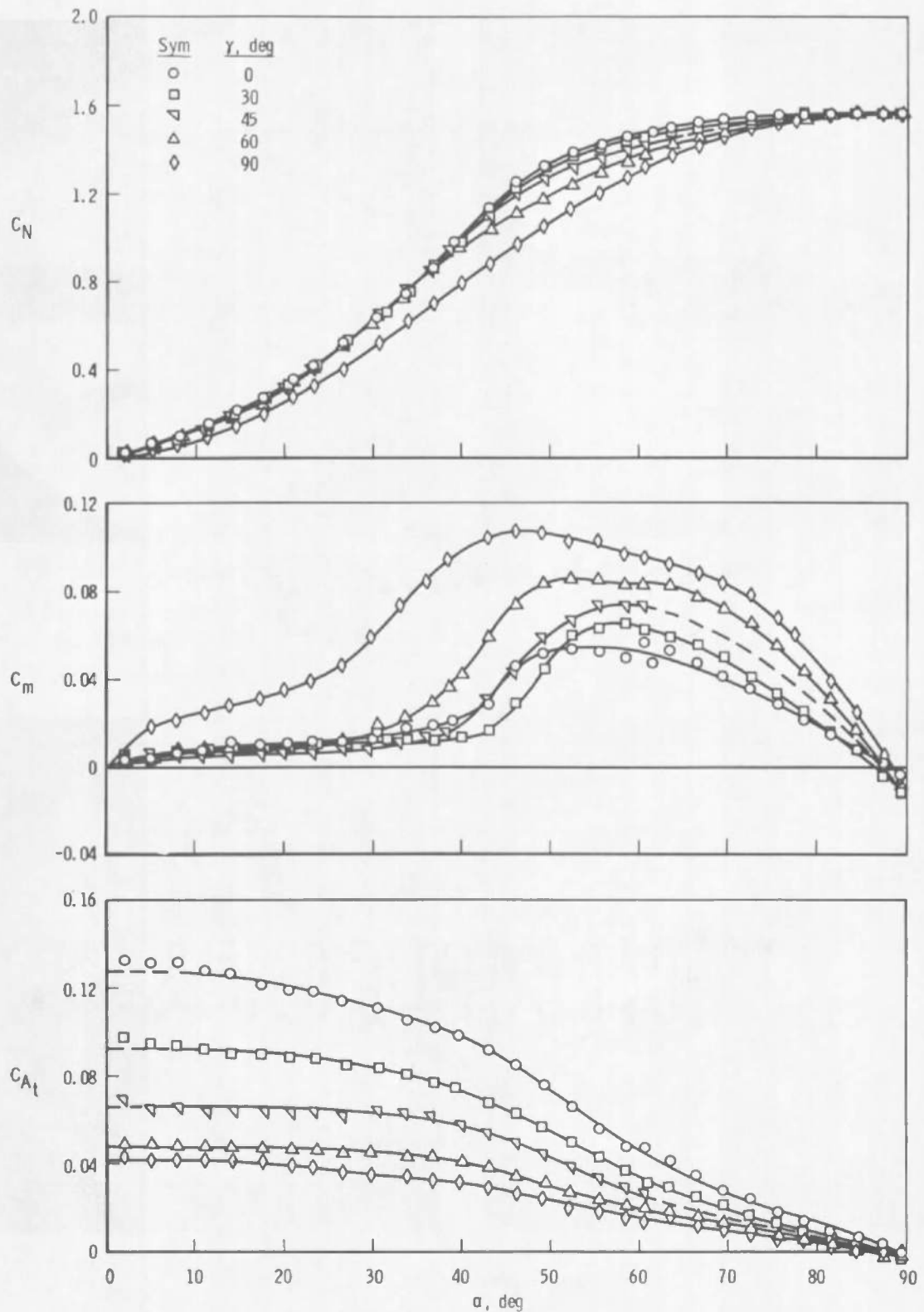


$\alpha = 37 \text{ deg}$
45-deg Balance-Model
Adapter, 0.50 Scale



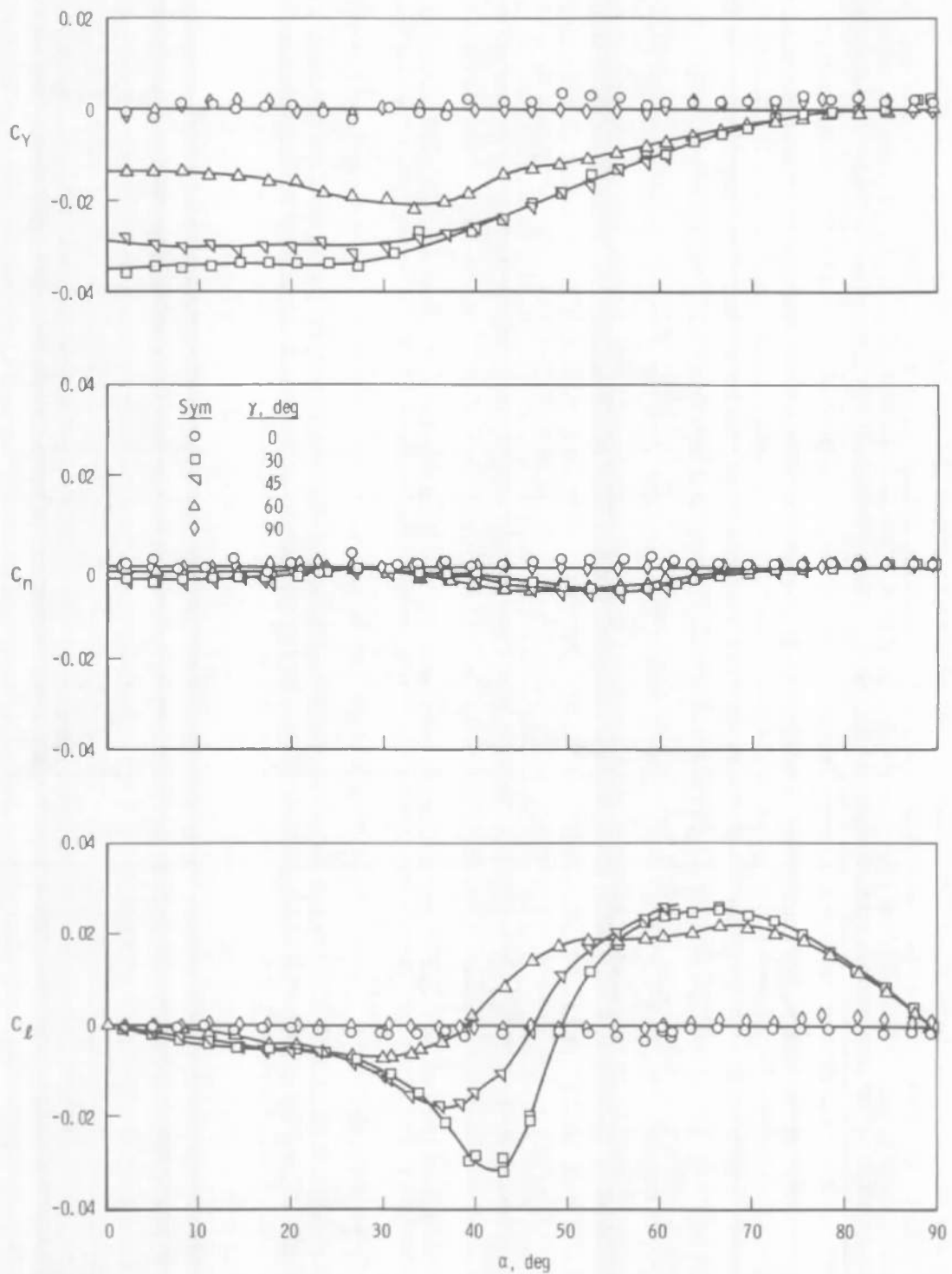
$\alpha = 90 \text{ deg}$
75-deg Balance-Model
Adapter, 0.50 Scale

Fig. 4 Typical Schlieren Photographs, Configuration M_2 Force Models, $\gamma = 0$



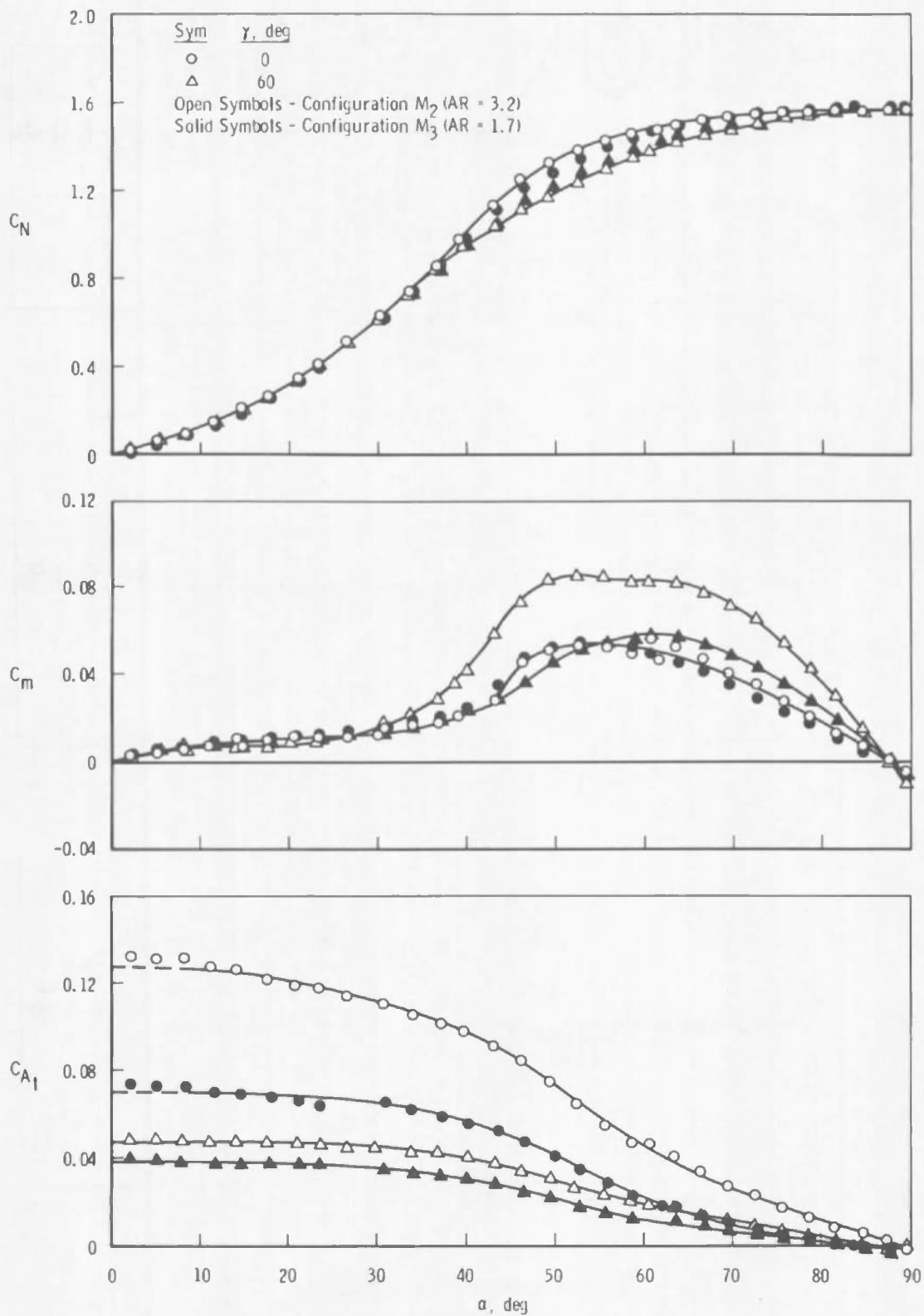
a. Longitudinal Stability and Axial Force

Fig. 5 Aerodynamic Characteristics of Configuration M_2 (AR = 3.2)



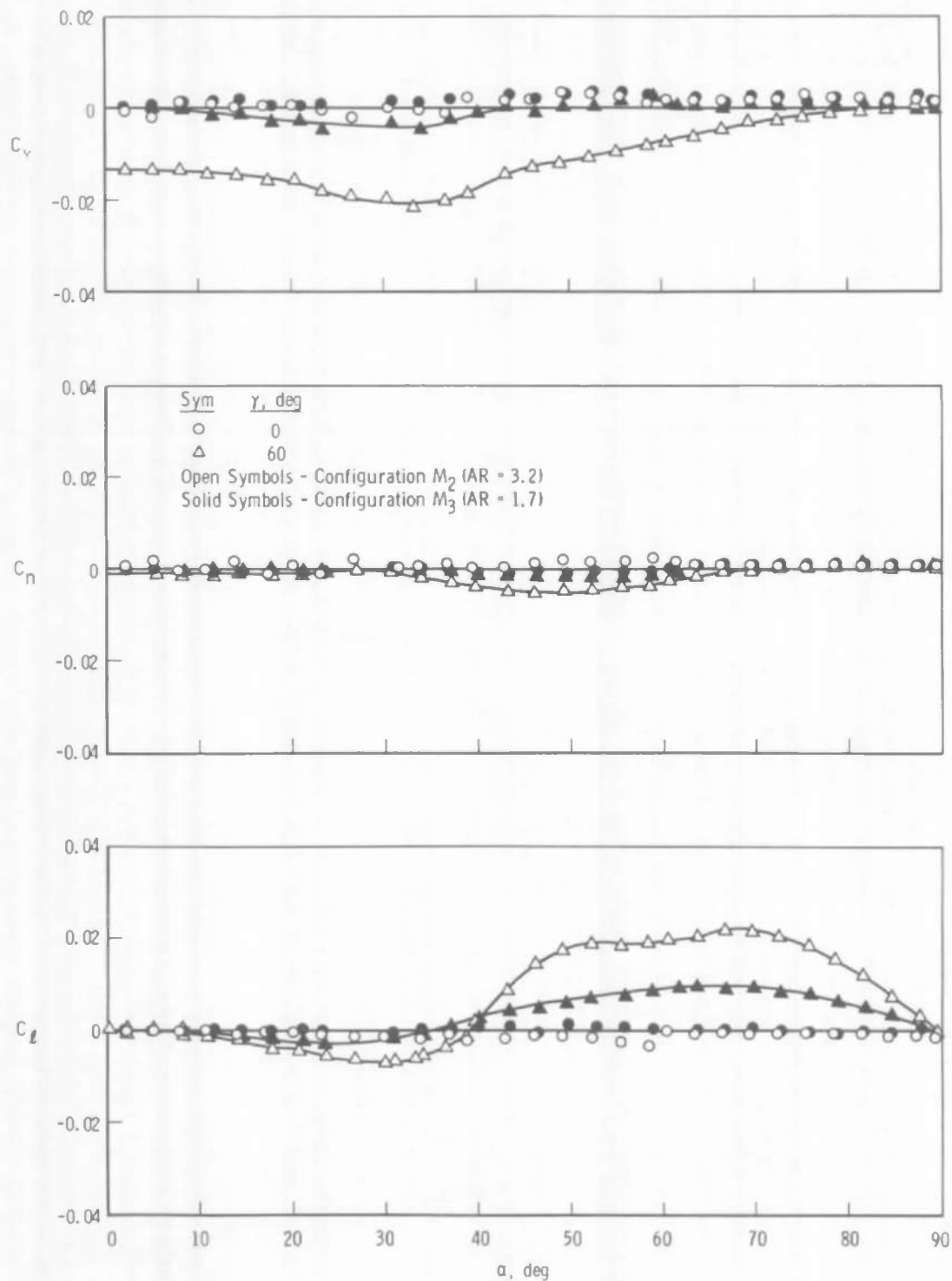
b. Directional and Lateral Stability

Fig. 5 Concluded



a. Longitudinal Stability and Axial Force

Fig. 6 Effect of Aspect Ratio on Aerodynamic Characteristics



b. Directional and Lateral Stability

Fig. 6 Concluded

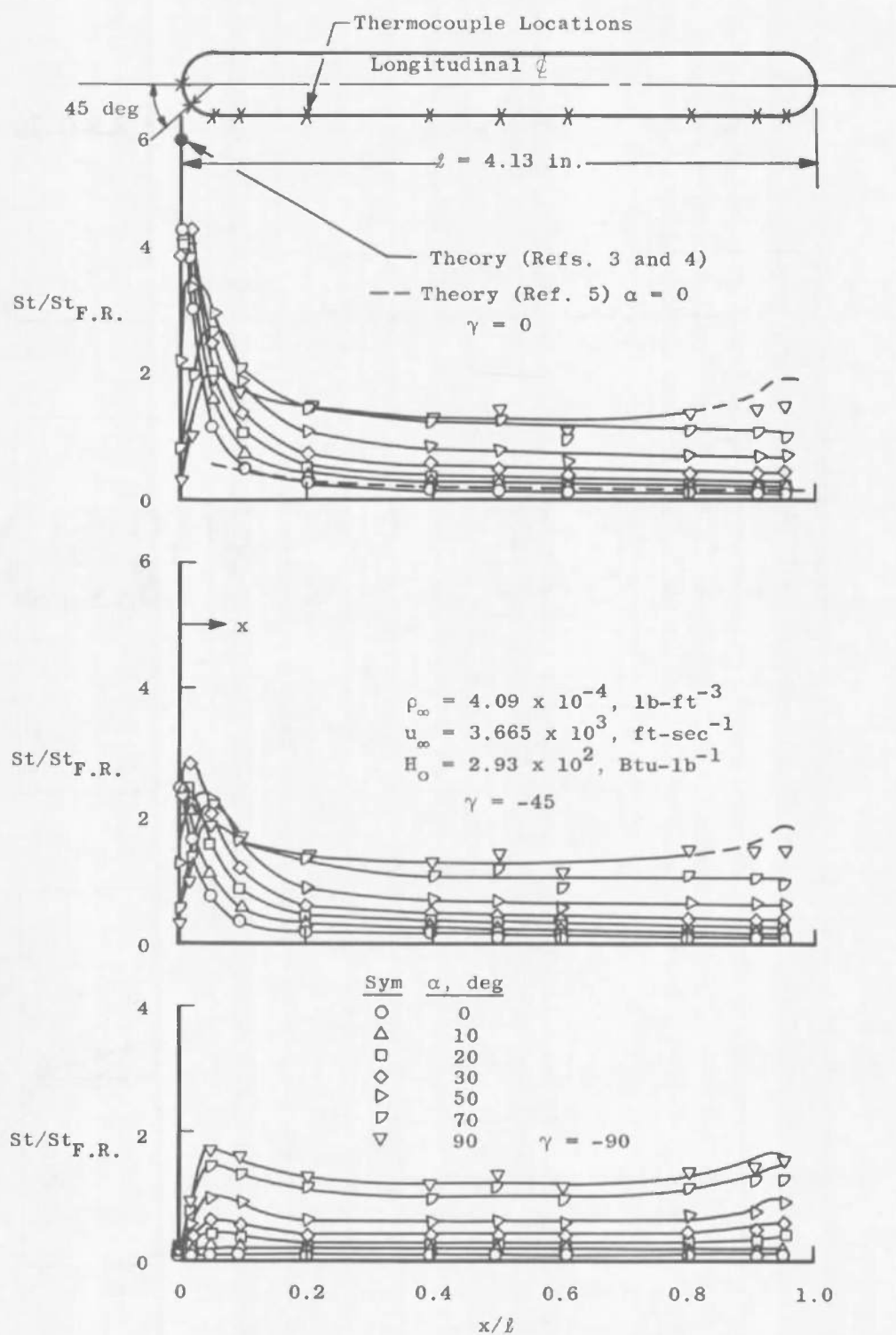


Fig. 7 Heat-Transfer Distributions along the Longitudinal Center-line of Configuration M_2 , $\gamma = 0, -45$, and -90 deg

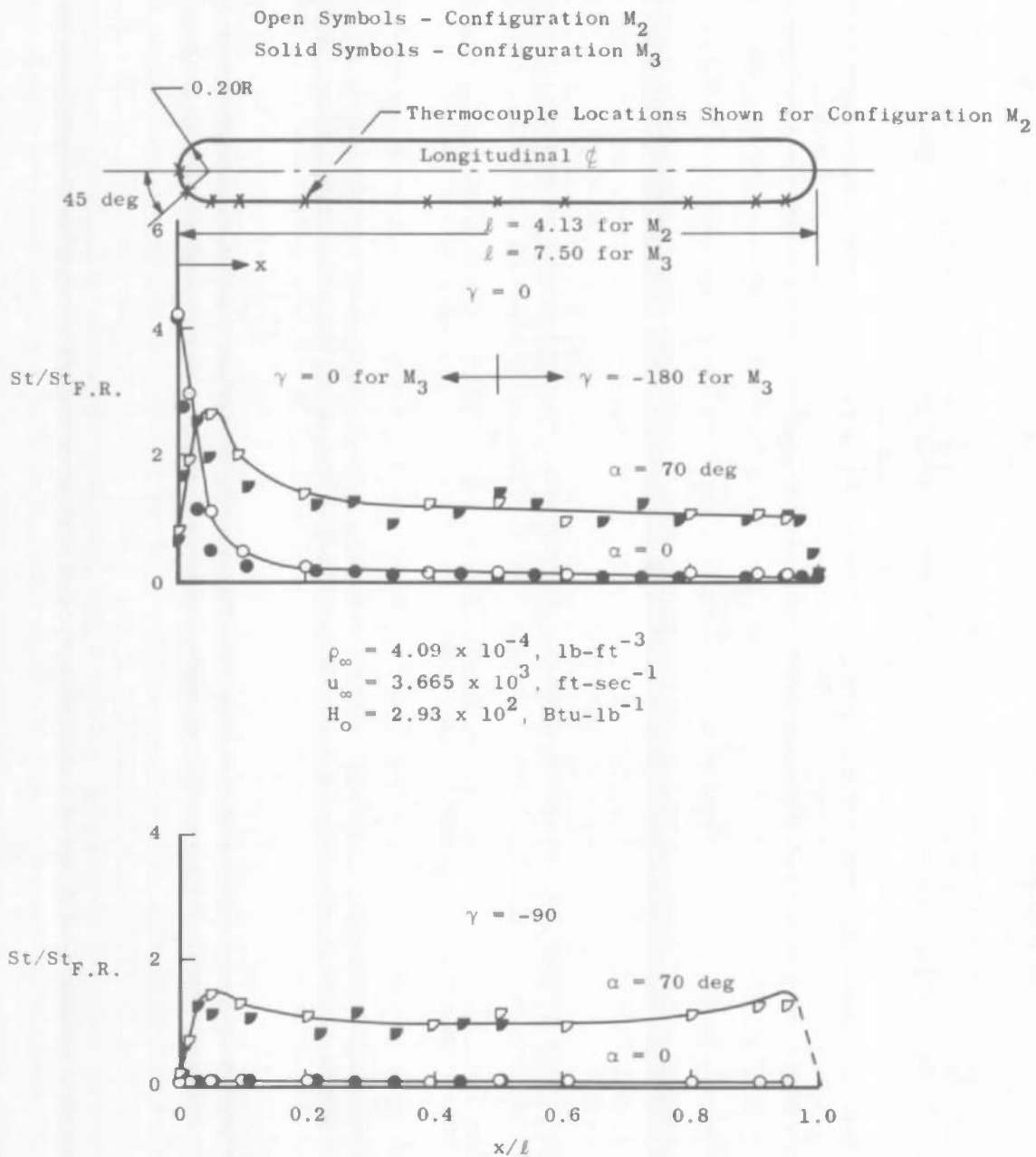


Fig. 8 Effect of Aspect Ratio on Longitudinal Centerline Heat-Transfer Distributions, $\gamma = 0$ and -90 deg

TABLE I
TEST SUMMARY

| | | <u>Force Tests</u> | | |
|---------------------------|---|--|-------------------------|--------------------------------|
| <u>Model</u> | <u>Re_l × 10⁻⁶</u> | <u>Balance-Model Adapter, deg</u> | <u>α-Range, deg</u> | <u>γ, deg</u> |
| 0.74 Scale M ₂ | 0.26 ↓ | 8 22.5 | -7 to 23 7.5 to 37.5 | 0, 15, 30, 45, 60, 75, 90 ↓ |
| 0.74 Scale M ₃ | 0.46 | 8 | -7 to 23 | |
| 0.50 Scale M ₂ | 0.26 ↓ | 45 75 | 30 to 60 60 to 90 | 0, 15, 30, 60, 90 |
| 0.37 Scale M ₃ | 0.46 ↓ | 45 75 | 30 to 60 60 to 90 | 0, 15, 30, 45, 60, 75, 90 ↓ |
| | | <u>Heat-Transfer Tests</u> | | |
| <u>Model</u> | <u>Re_l × 10⁻⁶</u> | <u>α, deg</u> | <u>γ, deg</u> | |
| 0.40 Scale M ₂ | 0.22 | 0, 5, 10, 20, 30, 40, 50, 60, 70, 80, 85, 90 | 0, -45, -72.5, -90 | |
| 0.40 Scale M ₃ | 0.40 | 0, 5, 10, 20, 30, 40, 50, 60, 70 | 0, -60.2, -90, -180 | |
| | | 0, 5, 10, 20, 30, 40, 50, 60, 70, 75, 80, 85 | -240 | |

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| 13. ABSTRACT Selected test results are presented to show the effect of aspect ratio on the aerodynamic and heat-transfer characteristics of the SNAP-29 fuel block which is a flat plate configuration with cylindrical edges. Static-force and moment and heat-transfer data were measured on models having aspect ratios of 1.7 and 3.2 at angles of attack from 0 to 90 deg and yaw rotations from 0 to 90 deg. The tests were conducted at Mach number 8 and Reynolds numbers from 0.22 to 0.46 million, based on model length. This document is subject to special export controls and each transmittal to foreign governments or foreign nationals may be made only with prior approval of U. S. Atomic Energy Commission, Sandia Base, Albuquerque, New Mexico, 87115. | | | |

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1. Fuel Blocks

2. Nuclear reactors -- Drop 29

3 " " -- Heat Transfer

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